

BELLCOMM, INC.

1100 Seventeenth Street, N.W. Washington, D. C. 20036

SUBJECT: Plasma Radiation Shielding
of Spacecraft - Case 710**DATE:** November 6, 1967**FROM:** A. C. BuffalanoABSTRACT

The plasma radiation shield is a scheme for shielding a spacecraft from MeV protons during a solar flare. Using a combination of electric and magnetic fields, the plasma radiation shield promises an order of magnitude weight advantage over conventional solid shielding.

It is not at all certain, however, that the scheme will work or be integrable in a spacecraft. The physics and some of the problems associated with the device are discussed.

(NASA-CR-92810) PLASMA RADIATION SHIELDING
OF SPACECRAFT (Bellcomm, Inc.) 9 p

N79-72311

00/18 Unclas
11050

FF No. 602(A)

CL-92810

(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

BELLCOMM, INC.

1100 Seventeenth Street, N.W. Washington, D. C. 20036

SUBJECT: Plasma Radiation Shielding
of Spacecraft - Case 710**DATE:** November 6, 1967**FROM:** A. C. BuffalanoMEMORANDUM FOR FILEINTRODUCTION

During a solar flare, large fluxes of high energy particles are exploded from the chromosphere into the solar system. These energetic particles, particularly protons, constitute a radiation problem which may be critical for extended interplanetary missions. The most obvious way to shield astronauts from the radiation is to provide a material shell to stop the incident particles. There are, however, alternate schemes which have been considered. Pure electrostatic shielding relies on charging the vehicle to a potential high enough to repel the oppositely charged particles. Such a scheme collects and accelerates particles of the opposite sign, however, and appears unfeasible. A pure magnetic scheme surrounds the vehicle with a magnetic field and deflects charged particles of both signs in the same way that the geomagnetic field deflects cosmic rays. Both of these schemes have been discussed in a prior Bellcomm Memorandum for File.⁽¹⁾

The purpose of this memorandum is to discuss a third scheme, the plasma radiation shield which is currently being studied at the Avco-Everett Research Laboratory by Dr. Richard Levy.⁽²⁾

THE PLASMA RADIATION SHIELD

Figure 1 shows a weight comparison of the plasma radiation shield, pure magnetic shielding and solid shielding. The weights are based on equal doses behind the shields with a design proton energy of 200 MeV. It is clear that the advantage of pure magnetic shielding over solid shielding appears only when large volumes are being shielded and then is not even an order of magnitude improvement. When one considers the complexity of the magnetic shield the benefits become marginal. The plasma radiation shield, however, appears to promise significant gains for the added complexity and therefore merits closer attention.

The plasma radiation shield uses a cloud of electrons surrounding the positively charged space vehicle to set up a large electrostatic field which repels protons. The cloud of electrons is held in place by a magnetic field. The electrons forming the cloud are ejected with low energies from the spacecraft as the magnetic field is being set up. Since the particles are, in some sense, tied to the field lines, they are carried into space by the increasing magnetic field. The spacecraft is thereby raised to a high potential and the region between the spacecraft and the cloud contains a large electrostatic field. The overall configuration of vehicle and cloud is neutral. Finally, the electric and magnetic fields act to cause an azimuthal particle drift which is hopefully part of a stationary equilibrium.

Consider the toroidal spacecraft shown in Figure 2. In theory, the cloud of electrons gives rise to a radial electric field E while the superconducting coils set up a nearly dipole magnetic field B , which is everywhere perpendicular to the electric field. In such a crossed field configuration, the electrons drift perpendicular to both the electric and magnetic fields, thus circling the spacecraft as shown. Drift speeds as high as half the speed of light are proposed. The possibility that such a configuration of fields and particles may survive for periods the order of two days long is what makes the concept interesting. It should be noted, of course, that the electrons have a much more complicated motion than that described. They spiral around the magnetic field lines as they drift in vehicle longitude, they collide and diffuse, and they have additional drifts due to the gradients of the electric and magnetic fields. Whether or not such a device can be made to work is problematical at this time.

PROBLEM AREAS

The plasma radiation shield is not without its problems. The configuration must be stable and effective for one or two days at a time and this places severe restrictions on the configuration's dynamics. The most catastrophic possibility is that the electron cloud might be unstable and collapse within the two day period. Questions of stability are extremely difficult to decide, especially in complex geometries with spatially varying fields, but what analysis has been done has been encouraging, although only the simplest geometries have been considered.

Laboratory experiments are presently being done in related geometries and these too have been encouraging. While such results are important, it is necessary to realize that no experiment to date has dealt directly with the plasma radiation shield.

Outgassing and vehicle leaking are other critical considerations. Neutrals outgassed or leaked from the spacecraft will be ionized rapidly by the electron cloud and the ions produced will be repelled by the shield, taking with them the energy gained by falling through the shield's electric field. Estimates show that leak rates larger than 10^{-6} - 10^{-4} grams of oxygen in two days would be enough to completely discharge the field. Leak rates of 2.2 pounds per day were experienced on Mercury vehicles and while no particular care was taken to reduce leaks, it is clear that many orders of magnitude separate the required and state-of-the-art leak rates.

Even if the shield were to operate, it would have to be satisfactorily integrated into the spacecraft. Controlling leaks is only one of the problems to be considered. It is clear, for example, that during a solar storm no attitude control or propulsive device could be used which had an exhaust. Thus, an ion engine would have to be shut down during a storm.

CONCLUSIONS

It seems highly unlikely that some simple calculation can be performed which will demonstrate that the concepts underlying the plasma radiation shield are unsound. A great deal of thought and effort has gone into the experiments and analyses and no such flaw has yet appeared. If the system is unstable or unworkable, it will only be found so after a great deal of effort. The problems associated with anomalous diffusion and containment are notoriously difficult to handle and usually require experimental rather than theoretical treatment. The controlled nuclear fusion program is an obvious example of the kinds of difficulties which are possible.

At present, this research is being funded by NASA, the Air Force, and the AEC which is interested in the containment possibilities of the idea. There is no question but that the research to date has been scientifically fruitful and that Avco-Everett has done its homework, nor is there any question but that solutions to difficult problems will have to be found before such a device is operational. As in controlled fusion, the risk must be measured in terms of the need and the magnitude of the reward. As Dr. Levy has written: "The nature of the plasma radiation shield is such that it is not by any means certain that it will be successful. However, if it is successful, it offers the

prospect of radiation shielding at a comparatively low cost in weight, provided that certain features of the device prove to be compatible with broader aspects of the space mission profile."(2)

Acknowledgement: The figures used in this memorandum were taken from the Avco-Everett Research Report Amp 179, Plasma Radiation Shielding, by R. H. Levy and S. James, December 1965.

1015-ACB-caw

A.C. Buffalano
A. C. Buffalano

Attachments
Bibliography
Figures 1-2

BELLCOMM, INC.

BIBLIOGRAPHY

- (1) F. G. Allen. "Magnetic and/or Electrostatic Shielding of Spacecraft," Bellcomm Memorandum for File, March 20, 1967.

The most complete discussion of the plasma radiation shield is to be found in:

- (2) R. H. Levy and F. W. French. "The Plasma Radiation Shield: Concept and Applications to Space Vehicles," Avco-Everett Research Laboratory, Research Report 258, April 1967.

Not only does this report deal with the many aspects of the plasma radiation shield, but it also contains a complete bibliography of 75 entries on active shielding in general.

A weight study of active shielding schemes is given in:

- (3) R. E. Bernert and Z. J. J. Stekly. "Magnetic Radiation Shielding Systems Analysis," Avco-Everett Research Laboratory, Research Report Amp 134, July 1964.

Stability considerations in crossed field configurations are found in:

- (4) O. Buneman, R. H. Levy and L. M. Linson. "Stability of Crossed-Field Electron Beams," Journal of Applied Physics, 37:3203, 1966.
- (5) R. H. Levy. "Effect of Coherent Radiation on the Stability of a Crossed-Field Electron Beam," Journal of Applied Physics, 37:119, 1966.
- (6) R. H. Levy. "Diocotron Instability in a Cylindrical Geometry," Physics of Fluids, 8:1288, 1965.

A fine systems review is given in:

- (7) R. H. Levy, and G. S. James. "Plasma Radiation Shielding," AIAA Journal, 2:1835, 1964.

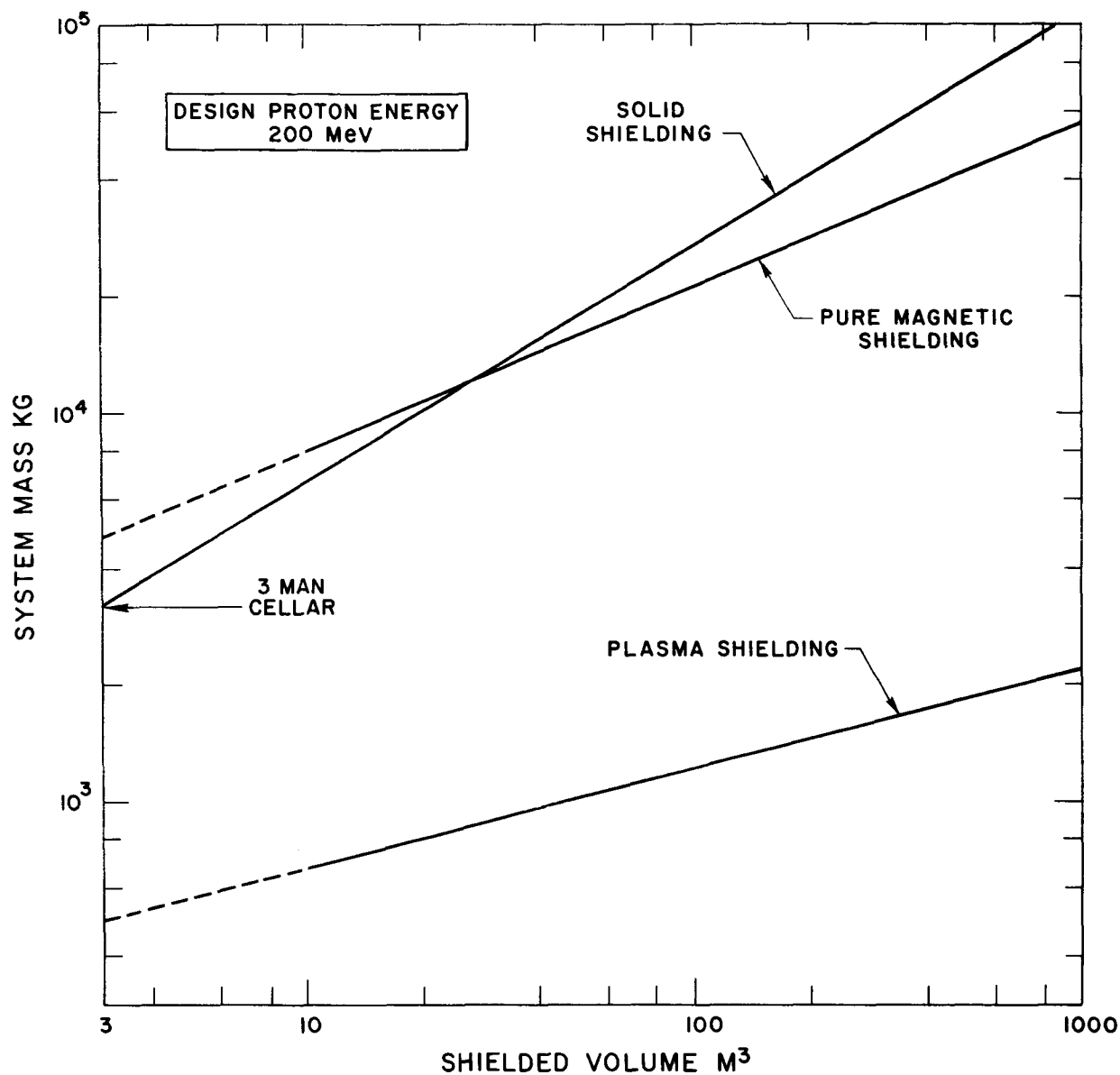


Fig. 1 Comparative weights of solid, pure magnetic, and Plasma Radiation Shields, for 200 MeV design proton energy. Note the large absolute weights of solid and pure magnetic shielding, and that, even in very large volumes, the Plasma Radiation Shield weighs less than a three man storm cellar. Note also that while the storm cellar "works", the Plasma Radiation Shield has not yet been shown to work.

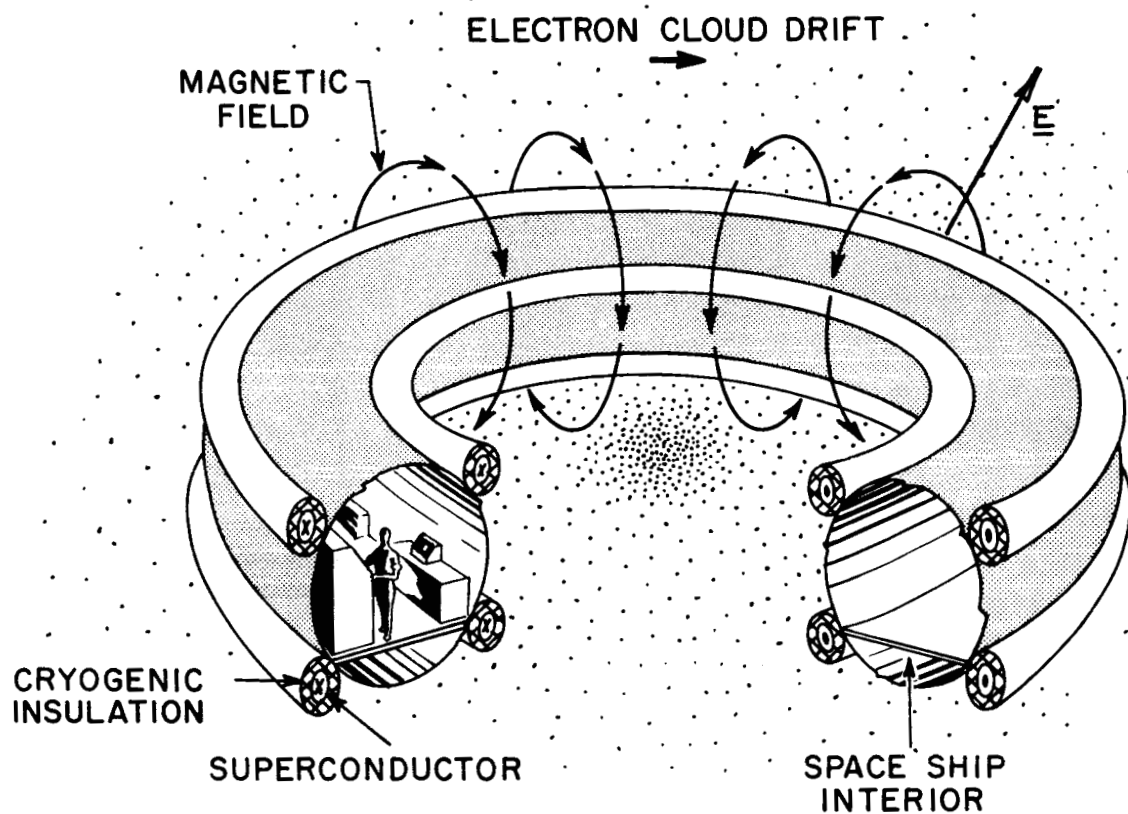


Fig. 2 The Plasma Radiation Shield. The four coil arrangement of the superconductor is more of a suggestion than a definite design. The electron cloud carries a negative charge equal and opposite to the positive charge on the space vehicle. Solar protons are reflected by the electric field between these charges, and are virtually unaffected by the magnetic field. The electron cloud drifts around the vehicle in the direction shown; the existence of this drift (see Fig. 4) makes the Plasma Radiation Shield a cousin of the crossed-field microwave magnetron.

BELLCOMM, INC.

Subject: Plasma Radiation Shielding
of Spacecraft - Case 710

From: A. C. Buffalano

Distribution List

NASA Headquarters

Messrs. P. E. Culbertson/MLA
F. P. Dixon/MTY
P. Grosz/MTL
E. W. Hall/MTS
H. Hall/MTX
T. A. Keegan/MA-2
D. R. Lord/MTD
M. J. Raffensperger/MTE
A. Reetz, Jr./RV-1
L. Reiffel/MA-6
L. Roberts/OART-M (2)
A. D. Schnyer/MTV
G. S. Trimble/MT
J. H. Turnock/MA-4
L. N. Werner/MTX

Bellcomm, Inc.

F. G. Allen
G. M. Anderson
A. P. Boysen, Jr.
J. P. Downs
D. R. Hagner
P. L. Havenstein
W. C. Hittinger
B. T. Howard
D. B. James
K. E. Martersteck
R. K. McFarland
J. Z. Menard
I. D. Nehama
G. T. Orrok
T. L. Powers
I. M. Ross
J. M. Tschirgi
R. L. Wagner
J. E. Waldo

All Members Division 101
Department 1023
Central File
Library